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YAKIMA RIVER BASIN HYDROLOGY AND WATER QUALITY DATA AND CALCULATIONS

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Public Health Service
Portland, Oregon

August 1963

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Details of illustrations in
this document may be better
studied on microfiche.

Engineering Operations Section

YAKIMA RIVER BASIN
HYDROLOGY AND WATER QUALITY
DATA AND CALCULATIONS

A Dubois Aug, 1963

I. PURPOSE

The purpose of this working paper is to set forth the data and information which has been collected in the Yakima Basin and to show calculations and methods of analysis used in making the various determinations appearing in Public Health Service reports on the Basin.

II. SURFACE WATER HYDROLOGY

A. Flows

The main sources of hydrology data are the U. S. Geological Survey Water Supply Papers. (1) Additional specific data were obtained from references (2) and (3) and from discussions with the U. S. Bureau of Reclamation in Yakima. Table 1 presents water right information for the major diversions in the Yakima Basin. Table 2 presents the average flows in the Yakima River at Cle Elum and Umtanum for the 1934-1960 period and at Parker and Kiona for the 1945-1960 period. This is the period of time following the development of the last major irrigation diversion in the Basin--the Roza Project. Table 3 presents information calculated by the Bureau of Reclamation concerning flows which would have occurred in certain reaches of the Yakima River with present development during the

1925 through 1955 period both with and without the Bumping Lake Enlargement Project. Table 4 presents flow information on Wapato Irrigation Project drains for the water years 1961 and 1962. Complete daily records for these water years are maintained in the Columbia River Basin Project files. Table 4 also contains estimates of flows in other drains discharging to the Lower Yakima Basin. These estimates were based on information obtained in references (2) and (4) and from field observation and measurement.

By comparing Tables 2 and 3, it can be seen that historically observed flows in the Yakima River at Parker do not correspond with flows calculated for these years by the Bureau of Reclamation. This situation arises because the major water users did not divert their full water right and because the system was not operated in such a manner as to minimize operational waste at Parker.

The beneficial flows accruing to water quality control from the proposed Bumping Lake Enlargement were calculated on the basis of information presented in Table 3. The difference between the calculated flow with the project and the calculated flow without the project were summed for each of the thirty-one years of record. Only those flows which totaled less than 800 cfs, or 48.3 thousand acre-feet per month, were considered beneficial for water quality control. Table 3 also presents the calculated beneficial flows to water quality control for each of the years 1925 through 1955. These data were then arranged in ascending order and plotted on both normal probability

paper and Gumbel paper, as shown in Figures 1 and 2. Both plots show that the one in ten year beneficial flow is approximately 43,000 acre-feet per year. This is the value for which alternate cost benefits were obtained for the Bumping Lake Enlargement Project for water quality control.

B. Travel Times

Table 5 [1/] lists average velocity and time of flow by section of the Yakima River from Easton to its confluence with the Columbia River. It was the opinion of the writer that, for certain sections of the Lower Yakima River, the average velocities were somewhat higher than actually exist during low flow conditions. For this reason, stream velocities at several points in the lower Yakima Basin were measured during September of 1962. The procedure for calculating velocities involved measurement of cross-section and flows at Grandview Bridge, Sunnyside-Mabton Bridge, the Granger Bridge and the Zillah-Toppenish Bridge. In addition, rudimentary dye and float studies were conducted in the vicinity of the Wapato-Donald Bridge and the Parker Bridge. The flows at Parker during this study were in the neighborhood of 400 cfs. Table 6 presents the estimated velocities and travel times in the Yakima River between Cle Elum and its confluence with the Columbia River. Travel times in the reach between Yakima and Prosser were based on results of the two-day Public Health Service study. Other travel times were based on those taken from reference (4).

1/ Table 5 is taken from "An Investigation of Pollution in the Yakima River Basin", Washington State Pollution Control Commission, Technical Bulletin No. 9, Summer, 1951. p. 23.

C. Calculation of Re-oxygenation Constant (k_2)

Two methods of calculating k_2 were investigated before the final selection of the O'Connor equation was made. The Churchill equation--

$$k_2 = \frac{5.026U^{.969}}{H^{1.673}}$$

where U equals velocity and H equals stream depth--was found to give uniformly higher k_2 rates. It was decided to use the O'Connor equations on the basis of the fact that it provided the most conservative values. O'Connor's equations are:

$$k_2 = \frac{480\ (D_L)^{1/2}S^{1/4}}{H^{5/4}}$$

for non-isotropic flow, and:

$$k_2 = \frac{(D_L U)^{1/2}}{2.31H^{3/2}}$$

for isotropic flow, where D_L is the diffusion coefficient, U is velocity, H is stream depth, and S is stream slope. The non-isotropic equation was used where depth was less than five feet, and the isotropic equation was used when stream depth exceeded five feet. Table 8 presents the calculated k_2 by reach for two different flow assumptions.

III. ORGANIC WASTE LOADING

A. Wastes

Information on the strength and quantity of municipal and industrial wastes in the Yakima Basin was obtained from references (4), (5), and (6), from the unpublished 1962 Inventory of Municipal Waste Facilities, and from field measurement and observation. Table 9 shows present, 1985 and 2010 municipal and industrial waste loadings both before and after treatment for each of the major communities in the Basin. Projections of municipal and industrial waste loading were made on the basis of the economic study prepared by the Columbia River Basin Project Economic Studies Group. (7) The assumption of 85 percent treatment of municipal wastes was used for all communities and an assumption of 85 percent treatment of industrial wastes in the cities of Yakima and Ellensburg was used. Ninety percent treatment of industrial waste was used in all other communities in the Basin because of the availability of large land areas for lagoon and spray irrigation treatment.

Calculation of individual industrial waste loads was as follows:

Yakima Industrial Waste Sewer:

Present Load: 240,000 P.E. (see p. 111 of reference (5).)

Growth rate: 1963-1985 — 3.5 percent (23 year factor = 2.20.)

Growth rate: 1985-2010 — 2.2 percent (25 year factor = 1.72.)

1985 Load: 2.2 x 240,000 = 530,000 P.E.

2010 Load: 530,000 x 1.72 = 910,000 P.E.

Waste Load from Projected Hardboard Mills:

Present Load: Zero.

1985 Load: Assume one 150 ton/day mill with waste loading of 15 pounds of BOD per ton of pulp = 2,250 pounds of BOD/day; 2,250 divided by .167 = 13,500 P.E.

2010 Load: Assume two 150 ton/day plants = 27,000 P.E.

Waste Load from Blue Ribbon Growers Company:

Present Load: From Washington Pollution Control Commission permit: maximum monthly waste discharge = 24.67 million gallons (0.8 MGD); and assume 1500 parts per million five-day BOD, which is the same as the Yakima industrial wastes sewer. Waste load = $\frac{1,500 \times 0.8 \times 8.34}{.167}$ = 60,000 P.E.

1985 Load: (Growth factors same as for industrial waste sewer) 60,000 x 2.2 = 132,000

2010 Load: 3.78 x 60,000 = 225,000 P.E.

Total Industrial Waste Loading for Yakima Area:

Present Load: 240,000 + 0 + 60,000 = 300,000

1985 Load: 530,000 + 13,500 + 132,000 = 675,500 P.E.

2010 Load: 910,000 + 27,000 + 225,000 = 1,162,000 P.E.

The industrial wastes listed above are for the late summer months during the fruit and vegetable canning season and are the maximum waste loads generated in the Yakima area during the year. Other wastes in the Yakima area are considered inconsequential for long-term planning purposes and were neglected.

Stokely-Van Camp of Ellensburg:

Present Load: .96 MGD (from WPCC permit; this includes cooling water) and an assumed BOD 1,100 ppm = 50,000 P.E.

1985 Load: 50,000 x 2.2 = 110,000 P.E.

2010 Load: 110,000 x 1.72 = 190,000 P.E.

California Packing Company at Toppenish:

Present Load: 1 MGD (from WPCC permit data) and an assumed BOD of 1,500 ppm is a waste loading of 75,000 P.E.

1985 Load: 75,000 x 2.2 = 165,000 P.E.

2010 Load: 165,000 x 1.72 = 284,000 PE

Stokely-Van Camp at Zillah:

Present Load: 1.08 MGD (measured on October 10, 1962 by WPCC personnel and is approximately twice the amount allowed in the WPCC permit) and a BOD of 580 ppm (highest of several BOD's measured by WPCC and PHS surveys) gives a waste loading of 32,000 P.E.

1985 Load: 2.2 x 32,000 = 70,500.

2010 Load: 70,500 x 1.72 = 121,000.

Grandview Industrial Wastes:

Present Load: 1.45 MGD (from sum of WPCC industrial waste discharge permits) and assumed strength of 1,500 ppm BOD, gives a waste loading of 109,000 P.E.

1985 Load: 109,000 x 2.2 = 240,000 P.E.

2010 Load: 240,000 x 1.72 = 413,000 P.E.

Prosser Industrial Wastes:

Present Load: 1.4 MGD (from measured flows by WPCC of the potato processing plant and the Prosser Packers' Company) and assumed BOD of 760 ppm from measurements made by WPCC and PHS. Present load = 50,000 P.E.

1985 Load: 50,000 x 2.2 = 110,000 P.E.

2010 Load: 110,000 x 1.72 = 189,000 P.E.

The waste loadings listed above are intended to represent maximum rather than average conditions. In general, it was attempted to use the most conservative (highest) waste load expected from any particular location. The purpose of using these conservative estimates was to obtain the worst possible organic loading situation, recognizing that, even with this condition, dissolved oxygen problems probably would not result in the Yakima Basin.

The BOD of tributary streams and irrigation return drains was included in the dissolved oxygen calculations for the Yakima Basin.

Table 10 lists the BOD's used in these calculations for each of the major streams and drains. Values for this table were obtained from reference (4) and field measurements made by the Public Health Service and the Washington Pollution Control Commission. BOD of the tributaries and drains was found to vary significantly with time of day and also with time of year. The generalized figures listed in Table 10 were generally conservative in that the higher, but not necessarily the highest, BOD's were used. It is assumed that the BOD measured in these tributaries and drains is from natural vegetation, fertilizers, etc.

B. Deoxygenation Rate (k_1)

In general, k_1 rate for various wastes and for various reaches of the river was calculated by the method established by Dr. E. C. Tsivoglou of Robert A. Taft Sanitary Engineering Center. The samples were collected and placed in an ice chest, then shipped by air to the Portland laboratory for analysis. In most cases, the BOD's were set up in the lab the same day that they were collected in the field. In many cases, erratic results were obtained and it was difficult to arrive at a calculated k_1 rate. A common occurrence was an apparent lag in the exertion of BOD of approximately one-half to one day. In general, enough samples were taken so that the k_1 rates were established with some degree of confidence.

C. Oxygen Sag Computations

Trial 1--The general assumptions used in Trial 1 were: a warm summer period during irrigation season but with low flow in the Yakima River and present waste loads in the quantities at which they presently reach the river. The assumption on waste loadings does not assume a degree of treatment but, instead, is based as nearly as possible on the actual amounts and strengths of waste reaching the stream. As an example, no wastes were assumed to have reached the river from non-overflow lagoons or from spray irrigation disposal sites.

Trial 2--This series of calculations was performed to test the oxygen conditions which might occur during a November period such as that which occurred in the year 1930--a very dry year and with waste loads approximately equivalent to those expected in 1985. It is assumed that the ground is frozen, thus making impossible employment of sprinkler irrigation for cannery wastes and yet with the canneries still in operation. Irrigation projects would have ceased diverting water during this hypothetical situation. Industrial wastes in the Yakima vicinity were assumed to all be diverted through the city's municipal sewage treatment plant as is planned according to reference (5).

The assumed treatment efficiency of this badly overloaded treatment plant was 40 percent BOD removal. During this period

it was assumed that the sugar refinery at Toppenish would have been in operation and that a load of 16,000 pounds of ultimate BOD was contributed by the refinery.

Trial 3--Trial 3 was conducted to test dissolved oxygen conditions in the Yakima Basin in the year 2010 with waste loads and treatment efficiencies predicted for that year. A dry year was assumed, and the enlarged Bumping Lake Project was assumed to not have been constructed. The time of year selected was August with its correspondingly high temperatures and peak food processing and irrigation return flow loads.

The three trial calculations described above presume the most severe conditions which can reasonably be assumed to occur in the future. The results indicate that, even with these severe conditions, critical dissolved oxygen levels would not result. This situation can be attributed largely to two factors: first, the fact that the large volume of high strength industrial wastes discharged to the Yakima River at Yakima enters the stream at a point where relatively large quantities of water remain in the stream; and second, the fact that the river has an extremely high calculated reaeration rate below the City of Yakima. Computations do not show the dissolved oxygen concentration which would occur in the major irrigation canals which originate immediately below Yakima. Trial 3, however, indicates that the BOD concentration of slightly more than five would result in the river and, hence, would be the BOD of the

water diverted into the canals. Even assuming no reaeration, it can be seen that septic conditions would not result in the irrigation canals.

The effects of algal photosynthesis and respiration on the dissolved oxygen content were not included in the calculations shown above. Surveys in the Yakima Basin have shown that there is a wide diurnal fluctuation in the dissolved oxygen content of the river in the reach between Yakima and the mouth. Dissolved oxygen values were observed to range from approximately 60 percent to 120 percent of saturation in the vicinity of Granger. As an indication of what may be considered the most severe situation, a calculation was made whereby the maximum observed deficit during a twenty-four hour period at Granger, presumably caused largely by algal respiration, was added to the deficit obtained in the oxygen sag calculations. This maximum situation showed a minimum dissolved oxygen of approximately 4.2 parts per million. It is recognized that this is an undesirably low dissolved oxygen concentration; however, there are several factors which tend to minimize the possibility of a serious oxygen situation arising. First, such low dissolved oxygen levels would last for only a matter of two to three hours out of each day; second, the tendency should be toward a reduction in nutrient concentrations in the Yakima River--hence, a reduction in algal activity; and third, the most conservative conditions which are reasonably practicable were applied to obtain the minimum dissolved

oxygen conditions mentioned above. An excellent discussion of the effects of algal activity on a stream which is at the same time receiving organic wastes is contained in reference (8). It is felt, however, that the complexity of multiple waste loads, highly variable flows, and inadequate stream velocity data preclude such a detailed analysis of the Yakima Basin. It is felt that considerable amount of additional data would be required to make such calculations practicable. In view of the discussions set forth above, it has been concluded that serious dissolved oxygen problems cannot be expected to result in the Yakima Basin.

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Table 1.--Rights of storage and power users diverting

Yakima Project Washington,
Unit - 1,0

			Type of Right	Notes on Pro-Rating	Jan.	Feb.	Mar.
above Naches	A.	Bruff, Wightman, Murphy, Stone-breaker	Storage (Disregard in Studies)	Pro-rate			
	B.	Kittitas	Storage	Pro-rate			
	C.	Cascade	Storage and Nat. Flow	Not pro-rate	1.8	1.7	5.7
	D	Westside	Nat. Flow	Not pro-rate			
			Storage	Pro-rate			
	E.	Ellensburg Power	Nat. Flow	Not pro-rate	9.2	8.3	9.2
	F	Terrace Heights	Nat. Flow(300 ac.ft. Storage Capacity)	Not pro-rate			
			Storage	Pro-rate			
	G.	Roza	Storage	Pro-rate			
	H	Selah-Moxee plus Moxee Sub "A"	Nat.Flow(Selah-Moxee has 2700 ac.ft.	Not pro-rate			
			Storage storage cap.)	Pro-rate			
Naches Tieton	I	Department of Agriculture	Storage (Disregard in Studies)	Pro-rate			
	J	Tieton	Storage	Not pro-rate			
			Storage	Pro-rate			91
				Total			
Naches	K	Cowiche-Moth	Storage Exchange (Disregard)	Pro-rate			
	L	Naches-Selah	Nat. Flow	Not pro-rate			
			Storage	Pro-rate			
below Tieton	M	Wapatox Power	Nat.Flow(based on 450 cfs,can be cut	Not pro-rate	27.7	25.0	27.
	N	5 Canals between Wapatox Hd.works&Tail-	Nat.Flow to 300 cfs)	Not pro-rate			
	O	Yakima Valley Canal race	Nat.Flow(4300 ac.ft. Storage Cap.)	Not pro-rate			
	P	City of Yakima	Nat. Flow	Not pro-rate			
			Storage	Pro-rate			
below Naches	Q	Union Gap Irrigation District	Storage and Nat. Flow	Not pro-rate			
			Storage	Pro-rate			
	R	Small Warren Act Users below Union Gap	Storage (Disregard in Studies)	Pro-rate			
	S	Broadway	Storage Exchange	Pro-rate			
	T	Wapato Indian Irrigation	Nat.Flow but must be maintained by	Not pro-rate			
			Storage stor. release	Pro-rate			
				Total			
	U	Sunnyside	Storage	Not pro-rate			
			Storage	Pro-rate			
				Total			
			TOTALS	Not Pro-rate	38.7	35.0	42.
				Pro-rate			
				Total	38.7	35.0	42.

...plemental Storage
acre-feet

Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		Total	Irrig. & Power Apr.-Oct.	Irrig. Only Apr.-Oct.
6.8	58.2	71.8	71.8	68.4	44.5	20.5			0.5	342.0		
9.0	9.2	9.0	9.2	9.2	2.9	2.3	1.8	1.8		63.6		
4.8	4.9	4.8	4.9	4.9	4.7	2.1				31.1		
0.5	1.5	1.5	1.6	1.6	1.5					8.2		
8.9	9.2	8.9	9.2	9.2	8.9	9.2	8.9	9.2		108.3		
0.4	0.3	0.4	0.4	0.4	0.2	0.1				2.2		
0.1	0.2	0.2	0.2	0.2	0.2					1.1		
37.5	50.2	71.2	71.3	71.3	45.0	22.5				375.0		
5.6	5.9	5.6	5.9	5.9	4.5	3.5				36.9		
0.3	0.3	0.5	0.5	0.5	0.3	0.1				2.5		
									20ac.ft.			
	15.4	14.9	15.4	15.4	14.9					76.0		
6.0	6.6	7.1	6.6	6.6	5.1					38.0		
6.0	22.0	22.0	22.0	22.0	20.0					114.0		
									3[illegible]ac.ft			
7.0	7.3	7.1	7.3	7.3	6.8	6.5				49.4		
0.7	0.8	0.9	1.1	1.1						4.6		
26.8	27.7	26.8	27.7	27.7	26.8	27.7	26.8	27.7		32[illegible].1		
5.9	6.2	5.9	6.2	6.2	4.4	3.1				37.9		
3.8	3.9	3.8	3.9	3.9	2.5	1.9				23.7		
1.2	1.3	1.2	1.3	1.3	0.8	0.6				7.7		
0.3	0.4	0.6	0.5	0.6	0.4	0.2				3.0		
3.2	3.4	3.2	3.4	3.4	2.3	1.8				20.7		
0.6	0.7	0.8	0.8	0.9	0.6	0.2				4.6		
									143ac.ft.			
0.1	0.1	0.1	0.1	0.1	0.1	0.1				0.7		
42.8	44.3	42.8	44.3	44.3	42.8	44.3				305.6		
31.5	73.5	70.0	80.5	73.5	21.0					350.0		
74.3	117.8	112.8	124.8	117.8	63.8	44.3				655.6		
49.1	48.6	47.1	48.6	48.6	47.1	28.8				315.9		
8.4	28.5	32.0	31.8	31.8	13.1					145.6		
55.5	77.1	79.1	80.4	80.4	60.2	28.8				461.5		
1[illegible].2	1[illegible].6	1[illegible].2	1[illegible].7	1[illegible].7	1[illegible].5	132.0	37.5	38.7		1405.1	1212.6	957.9
22.3	227.0	25[illegible].7	2[illegible].8	2[illegible]6.[illegible]	131.8	43.[illegible]				1275.3	1275.3	1275.3
229.3	418.6	432.2	454.2	444.3	301.4	1[illegible].[illegible]	37.5	38.7		2[illegible]80.4	2487.9	2232.2

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TABLE 2

Average Flow in Yakima River
(cfs)

Station	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Cle Elum[a/]	815	675	1,278	1,031	858	826	1,576	2,806	3,109	2,643	2,663	1,922
Umtanum[a/]	1,247	1,150	1,957	1,618	1,566	1,939	3,430	4,527	4,084	2,864	2,837	2,280
Parker[b/]	1,241	2,659	3,822	2,822	3,025	3,023	3,342	5,418	4,576	1,022	379	394
Kiona[b/]	2,743	3,815	4,770	3,845	4,158	4,426	5,082	6,998	6,734	2,418	1,750	2,021

a/ 1934-1960.
b/ 1945-1960.

TABLE 3

Yakima River Flow at Parker

(1,000's of acre-feet per month)

Year		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	D
1925	A						54.6	14.4	14.4	14.0	15.4	54.7	109.1	
	B						54.6	7.7	7.7	7.4	7.7	48.7	108.4	
	C						0	6.7	6.7	6.6	7.7	6.0	0.7	27.7
1926	A	92.8	108.5	145.5	13.7	11.1	10.7	14.4	14.5	14.0	15.4	78.8	147.7	
	B	84.2	100.3	141.3	12.2	7.7	7.4	7.8	7.0	7.4	7.7	78.9	155.2	
	C	8.6	8.2	4.2	1.5	3.4	3.3	6.6	7.5	6.6	7.7	(0.1)	(7.5)	36.6
1927	A	88.5	100.5	155.1	102.0	50.4	179.4	14.4	14.4	14.0	72.6			
	B	85.2	97.9	155.1	94.5	84.2	263.4	7.7	7.7	18.4	74.8			
	C	3.3	2.6	0	7.5	(33.8)	(84.0)	6.7	6.7	(4.4)	(2.2)			9.0
1928	A					470.5	12.4	14.4	14.4	14.0	15.4	59.7	64.8	
	B					482.9	9.2	7.7	7.7	7.4	7.7	54.0	59.0	
	C					(12.4)	3.2	6.7	6.7	6.6	7.7	5.7	5.8	30.9
1929	A	60.8	63.3	80.0	10.7	11.1	10.7	14.4	14.4	14.0	15.4	41.9	60.5	
	B	53.5	57.6	71.5	7.4	7.7	7.4	7.7	7.7	7.4	7.7	33.0	54.7	
	C	7.3	5.7	8.5	3.3	3.4	3.3	6.7	6.7	6.6	7.7	8.9	5.8	37.7
1930	A	52.0	98.1	95.5	45.6	11.1	10.7	14.4	14.4	14.0	15.2	53.7	53.8	
	B	46.2	90.8	87.8	55.7	7.7	7.4	7.8	7.4	7.4	7.5	47.2	45.7	
	C	5.8	7.3	7.7	(10.1)	3.4	3.3	6.6	7.0	6.6	7.7	6.5	8.1	34.6
1931	A	54.3	66.6	11.5	10.7	11.1	10.7	14.5	14.4	15.8	18.6	71.3	64.9	
	B	47.6	59.6	1.9	7.4	7.7	7.4	7.5	6.8	8.4	7.7	65.5	59.0	
	C	6.7	7.0	9.6	3.3	3.4	3.3	7.0	7.6	7.4	10.9	5.8	5.9	52.5

A - With Dumping Lake Enlargement.
B - Without Dumping Lake Enlargement.
C - Difference.
D - Annual beneficial augmentation.

NOTE: Figures in parentheses are minus figures.

TABLE 3 (Continued)

Year		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	D
1932	A	94.6	116.2	287.6	121.5	104.5	81.3	14.4	14.4	14.0	15.4	283.2	170.6	
	B	88.0	118.4	301.1	119.3	158.7	152.7	7.7	7.7	7.4	7.7	307.1	179.5	
	C	6.6	(2.2)	(13.5)	2.2	(54.2)	(71.4)	6.7	6.7	6.6	7.7	(23.9)	(8.9)	27.7
1933	A	185.0	94.3	100.3	91.8	197.6	468.4	43.3	14.4	129.2	200.7	286.8	968.0	
	B	185.9	88.4	94.5	84.9	231.9	544.2	92.5	7.7	126.5	215.0	303.1	1015.2	
	C	(0.9)	5.9	5.8	6.9	(34.3)	(75.8)	(49.2)	6.7	2.7	(14.3)	(16.3)	(47.2)	6.7
1934	A	615.8	348.6	510.8	358.7	108.0	10.7	14.4	14.4	14.0	15.7	204.3	153.1	
	B	615.8	348.4	511.0	358.7	108.0	7.4	7.7	7.7	7.4	7.7	232.9	149.1	
	C	0	0.2	(0.2)	0	0	3.3	6.7	6.7	6.6	8.0	(28.6)	4.0	31.3
1935	A	300.6	249.5	129.2	10.7	224.2	222.1	14.4	14.4	14.0	15.4	66.9	58.4	
	B	300.9	254.5	127.7	7.4	230.5	222.9	7.7	7.7	7.4	7.7	61.2	52.6	
	C	(0.3)	(5.0)	1.5	3.3	(6.3)	(0.8)	6.7	6.7	6.6	7.7	5.7	5.8	27.7
1936	A	68.0	51.9	141.3	232.7	318.4	242.4	14.4	14.4	14.0	15.4	60.0	74.4	
	B	59.4	43.8	132.8	230.4	385.2	242.4	7.7	7.7	7.4	7.7	52.1	68.6	
	C	8.6	8.1	8.5	2.3	(66.8)	0	6.7	6.7	6.6	7.7	7.9	5.8	27.7
1937	A	62.4	54.9	110.0	69.8	14.7	189.8	14.4	14.4	14.0	15.4			
	B	56.6	49.6	101.5	61.4	12.3	268.5	7.7	7.7	7.4	7.7			
	C	5.8	5.3	8.5	8.4	2.4	(78.7)	6.7	6.7	6.6	7.7			30.1
1938	A						201.8	14.4	14.4	14.0	15.4	81.2	94.7	
	B						201.8	7.7	7.7	7.4	7.7	75.5	88.8	
	C						0	6.7	6.7	6.6	7.7	5.7	5.9	27.7

A - With Dumping Lake Enlargement.
B - Without Dumping Lake Enlargement.
C - Difference.
D - Annual beneficial augmentation.

NOTE: Figures in parentheses are minus figures.

TABLE 3 (Continued)

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	D
1939	A	121.0	75.5	121.7	10.7	14.2	10.7	14.4	14.4	14.0	15.4	59.9	91.0	
	B	112.4	68.8	113.1	8.3	49.7	7.4	7.7	7.7	7.4	7.7	54.2	93.1	
	C	8.6	6.7	8.6	2.4	(35.5)	3.3	6.7	6.7	6.6	7.7	5.7	(2.1)	33.4
1940	A	64.2	105.2	159.6	21.9	13.1	10.7	14.4	14.4	14.0	14.4	68.0	104.1	
	B	55.9	97.4	161.7	39.3	8.0	7.4	7.7	7.8	7.5	7.6	62.2	99.2	
	C	8.3	7.8	(2.1)	(17.4)	5.1	3.3	6.7	6.6	6.5	6.8	5.8	4.9	35.0
1941	A	69.4	78.7	122.0	15.2	11.1	10.7	14.4	15.4	14.8	15.7	89.4	137.1	
	B	63.6	72.2	114.4	14.3	7.7	7.5	7.7	7.8	7.4	7.7	86.7	145.7	
	C	5.8	6.5	7.6	0.9	3.4	3.2	6.7	7.6	7.4	8.0	2.7	(8.6)	37.4
1942	A	72.1	80.6	74.1	41.4	11.1	10.7	14.4	14.4	14.0	15.3	99.5	129.8	
	B	65.8	74.7	66.5	42.4	7.7	7.4	7.7	7.7	7.4	7.6	103.1	131.0	
	C	6.3	5.9	7.6	(1.0)	3.4	3.3	6.7	6.7	6.6	7.7	(3.6)	(1.2)	34.4
1943	A	131.7	106.5	144.8	351.2	15.7	188.4	14.4	14.4	23.5	15.8	74.1	106.0	
	B	126.2	102.8	146.3	360.4	47.2	260.0	7.7	7.7	27.6	8.1	69.4	91.4	
	C	5.5	3.7	(1.5)	(9.2)	(31.5)	(71.6)	6.7	6.7	(4.1)	7.7	4.7	14.6	17.0
1944	A	58.4	63.6	69.1	10.7	11.1	10.7	14.4	14.4	14.0	15.3	65.9	69.2	
	B	52.4	58.3	62.0	7.4	7.7	7.4	7.8	7.8	7.5	7.9	60.1	63.3	
	C	6.0	5.3	7.1	3.3	3.4	3.3	6.6	6.6	6.5	7.4	5.8	5.9	37.1
1945	A	124.4	123.9	66.3	10.7	17.0	10.7	14.4	14.4	14.0	15.4	89.0	91.4	
	B	123.3	128.9	60.3	7.4	7.7	7.4	7.7	7.7	7.4	7.7	83.3	85.6	
	C	1.1	(5.0)	6.0	3.3	9.3	3.3	6.7	6.7	6.6	7.7	5.7	5.8	43.6

A - With Dumping Lake Enlargement.
B - Without Dumping Lake Enlargement.
C - Difference.
D - Annual beneficial augmentation.

NOTE: Figures in parentheses are minus figures.

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TABLE 3 (Continued)

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	D
1946	A	109.6	75.6	141.1	125.8	173.6	166.8	14.4	14.4	18.2	18.0	79.0	317.3	
	B	105.0	70.3	139.7	120.4	241.1	241.0	7.7	7.7	21.0	10.3	88.4	336.8	
	C	4.6	5.3	1.4	5.4	(67.5)	(74.2)	6.7	6.7	(2.8)	7.7	(9.4)	(19.5)	18.3
1947	A	163.5	212.1	224.2	87.5	253.1	16.7	14.4	14.4	14.0	58.9	224.4	133.0	
	B	162.7	220.5	234.1	91.5	304.8	16.2	7.7	7.7	7.4	72.0	240.1	135.7	
	C	0.8	(8.4)	(9.9)	(4.0)	(51.7)	0.5	6.7	6.7	6.6	(13.1)	(15.7)	(2.7)	20.5
1948	A	106.9	111.0	86.3	67.7	498.4	633.9	14.4	14.4	18.9	20.2	102.9	82.8	
	B	104.1	112.7	90.7	60.8	546.5	702.8	7.7	7.7	22.2	12.5	108.2	77.1	
	C	2.8	(1.7)	(4.4)	6.9	(48.1)	(68.9)	6.7	6.7	(3.3)	7.7	(5.3)	5.7	17.8
1949	A	60.6	87.8	222.7	279.2	704.2	302.8	14.4	14.4	20.7	29.5	276.7	157.7	
	B	54.8	83.7	225.0	278.6	774.4	302.8	7.7	7.7	24.1	21.8	294.4	157.7	
	C	5.8	4.1	(2.3)	0.6	(70.2)	0	6.7	6.7	(3.4)	7.7	(17.7)	0	17.7
1950	A	77.3	122.9	218.7	137.3	460.2	759.0	138.3	14.4	95.0	137.0	332.6	404.3	
	B	73.9	124.9	220.1	128.6	468.8	759.0	138.3	7.7	96.6	141.9	332.6	404.3	
	C	3.4	(2.0)	(1.4)	8.7	(8.6)	0	0	6.7	(1.6)	(4.9)	0	0	6.7
1951	A	235.6	474.7	208.8	308.4	613.7	231.8	14.4	14.4	14.0	43.1	104.3	93.6	
	B	235.6	474.7	207.3	306.9	616.7	231.8	7.7	7.7	7.4	35.4	102.7	89.2	
	C	0	0	1.5	1.5	(3.0)	0	6.7	6.7	6.6	7.7	1.6	4.4	27.7
1952	A	62.3	110.9	113.6	85.2	164.4	38.6	14.4	14.4	14.0	15.4	59.8	60.2	
	B	59.3	108.4	110.1	81.9	210.2	37.7	7.7	7.7	7.4	7.7	50.5	51.8	
	C	3.0	2.5	3.5	3.3	(45.8)	0.9	6.7	6.7	6.6	7.7	9.3	8.4	28.6

A - With Dumping Lake Enlargement.
B - Without Dumping Lake Enlargement.
C - Difference.
D - Annual beneficial augmentation.

NOTE: Figures in parentheses are minus figures.

TABLE 3 (Continued)

Year		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	D
1953	A	170.1	211.5	72.6	12.2	194.2	192.8	14.4	14.4	26.3	22.4	100.6	204.5	
	B	185.4	223.4	71.0	7.4	219.7	192.9	7.7	7.7	29.4	12.0	101.6	214.9	
	C	(15.3)	(11.9)	1.6	4.8	(25.5)	(0.1)	6.7	6.7	(3.1)	10.4	(1.0)	(10.4)	20.7
1954	A	128.5	149.4	122.0	58.8	516.2	365.1	140.0	14.4	137.5	64.6	191.6	90.6	
	B	128.8	147.8	124.3	50.0	533.1	365.1	140.0	7.7	138.8	69.5	192.2	80.8	
	C	(0.3)	1.6	(2.3)	8.8	(16.9)	0	0	6.7	(1.3)	(4.9)	(0.6)	9.8	6.7
1955	A	86.9	106.1	47.3	10.7	25.6	490.1	17.3	14.4	59.3	156.3	402.6	271.3	
	B	73.6	104.6	41.5	7.4	21.2	524.5	17.3	7.7	61.0	161.3			
	C	13.3	1.5	5.8	3.3	4.4	(34.1)	0	6.7	(1.7)	(5.0)			14.4

A - With Dumping Lake Enlargement.
B - Without Dumping Lake Enlargement.
C - Difference.
D - Annual beneficial augmentation.

NOTE: Figures in parentheses are minus figures.

TABLE 4

Average Flow by Month in Wapato Project Drains
(cfs)

Location	Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Satus Creek near Satus	1961	34	168	88	284	1410	609	142	96	91	78	87	114
	1962	41	44	159	140	271	292	210	106	70	86	97	164
Toppenish Creek near Alfalfa	1961	174	54	59	75	381	365	229	95	77	15	36	54
	1962	98	50	61	72	103	127	134	47	35	19	35	30
Marion Drain near Alfalfa ..	1961	393	289	240	205	280	286	425	598	377	107	105	124
	1962	412	282	237	218	197	195	422	474	374	76	183	64
South Drain near Satus	1961	9.3	13	7.7	8	217	27	78	71	66	74	63	104
	1962	14	8	6	5	6	12	57	87	72	75	85	84
East Toppenish Drain at Wilson Road	1961	34	17	14	6	6.6	11	33	50	55	47	68	58
	1962	34	16	10	9	9.5	10	30	56	64	54	66	62
McDonald Drain (S. D. #35) at Parton Road	1961	32	24	21	20	20	20	37	53	59	62	60	60
	1962	42	25	21	17	16	16	36	57	67	71	67	63
Coulee Drain at North Satus Road	1961	5.1						5.1	28	32	31.5	27	15
	1962	7.4	2.2					13	32	25	26	28.5	24
Drain 302 at Highway 3A	1961							9	15	25	22	26	27
	1962							13	25	25	22	27	25
Drain 303 at Looney Road ...	1961							10	11	16	6	17	10
	1962							11	25	19	9	12	16

TABLE 6

Travel Times in the Yakima Basin
during Summer Flow Conditions

Reach	Length (miles)	Velocity (mph)	Travel Time (hours)	Slope
Cle Elum to mouth of Wilson Creek near Ellensburg	35	3.9	9.0	.00265
Mouth of Wilson Creek to mouth of Naches River	31	3.7	8.3	.00237
Mouth of Naches River to Yakima STP outfall	5	2.5	2.0	.00305
Yakima outfall to Union Gap Bridge	4	3.4	1.2	.00246
Union Gap Bridge to Sunnyside Dam	4	3.8	1.1	.00246
Sunnyside Dam to Granger	19	1.4	14.0	.00227
Granger to Satus (town)	10	1.0	10.0	.000416
Satus to Mabton Bridge	3	0.5	6.0	.000416
Mabton Bridge to Prosser	18	0.8	22.5	.000416
Prosser to Chandler Power Plant	8	4.0	2.0	.00182
Chandler Power Plant to Kiona	8	3.5	2.3	.00135
Kiona to mouth	31	2.8	11.1	.00084

C.BIAC River Mile Index shows 13 miles

1982

TABLE 8

Reoxygenation Constants at 20° C.
(k_2 to the base 10)

Reach	Approximate Flow--(cfs)	k_2 (per day)	Approximate Flow--(cfs)	k_2 (per day)
Cle Elum-Ellensburg	1500 - 2500	1.2		
Ellensburg-Naches River	1500 - 2500	1.1		
Naches River-Yakima Outfall	1500 - 2500	0.8		
Yakima Outfall-Sunnyside Dam	1500 - 2500	0.8		
Sunnyside Dam-Zillah	50 - 250	1.3	500 - 600	1.0
Zillah-Granger	250 - 550	1.4	650 - 700	1.0
Granger-Satus	500 - 750	0.5		
Satus-Grandview	800 - 1300	0.2		
Grandview-Prosser	950 - 1450	0.3		
Prosser-Chandler	50	4.1		
Chandler-Kiona	800 - 1300	1.0		
Kiona-Richland	750 - 1300	0.6		

TABLE 9

Municipal and Industrial Waste Loads
Population Equivalents during the Late Summer

Location	Present		1985		2010		
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	
Roslyn-Cle Elum	2,700	Negligible	5,000	Negligible	7,400	Negligible	Untreated
	1,200	Negligible	750	Negligible	1,100	Negligible	Treated
Ellensburg	20,000	50,000	25,000	110,000	30,000	190,000	Untreated
	10,000	7,500	4,000	16,500	5,000	28,500	Treated
		91,400		161,250		262,000	
Kittitas	550	Negligible	600	Negligible	700	Negligible	Untreated
	170	Negligible	150	Negligible	150	Negligible	Treated
Naches	550	Negligible	800	Negligible	900	Negligible	Untreated
	190	Negligible	200	Negligible	250	Negligible	Treated
		1460		1750		2000	
Selah, Yakima, Union Gap	60,000	300,000	97,000	675,000	146,000	1,162,000	Untreated
	44,100	45,000	15,000	101,000	22,000	174,000	Treated
Moxee City	500	Negligible	600	Negligible	700	Negligible	Untreated
	350	Negligible	150	Negligible	200	Negligible	Treated
		449,950		883 750		1,504,400	
Wapato	2,400	Negligible	3,600	Negligible	4,000	Negligible	Untreated
	480	Negligible	550	Negligible	600	Negligible	Treated
Toppenish	5,100	75,000	6,400	165,000	7,300	284,000	Untreated
	1,270	5,000	1,250	16,500	1,250	28,400	Treated
Zillah	1,100	32,000	1,500	70,500	2,200	121,000	Untreated
	240	2,000	300	7,050	350	12,100	Treated

(Continued)

TABLE 9 (Continued)

Location	Present		1985		2010		
	Municipal	Industrial	Municipal	Industrial	Municipal	Industrial	
Harrah	280	Negligible	300	Negligible	400	Negligible	Untreated
	250	Negligible	100	Negligible	100	Negligible	Treated
Granger	1,350	Negligible	2,000	Negligible	2,900	Negligible	Untreated
	300	Negligible	350	Negligible	450	Negligible	Treated
		126,110		275,400		465,050	
Sunnyside	6,600	City Plant	15,000	City Plant	20,000	City Plant	Untreated
	1,000	City Plant	3,800	City Plant	5,000	City Plant	Treated
Mabton	1,000	Negligible	1,400	Negligible	2,000	Negligible	Untreated
	700	Negligible	210	Negligible	300	Negligible	Treated
Grandview	3,400	109,000	4,900	240,000	7,200	413,000	Untreated
	500	1,000	750	24,000	1,100	41,300	Treated
		123,200		290,060		489,100	
Prosser	2,700	50,000	3,100	110,000	3,500	168,000	Untreated
	500	500	500	11,000	550	18,900	Treated
		53,700		124,600		211,950	
Benton City	900	Negligible	1,700	Negligible	2,300	Negligible	Untreated
	360	Negligible	250	Negligible	350	Negligible	Treated
	1260		1950		2650		

TABLE 10

Tributary BOD Loads

Stream	5-Day BOD	Flow (cfs)
Roslyn Creek	4.0	4
Teanaway River	1.0	20
Wilson Creek	2.5	120
Selah Drain	10.0	5
Naches River	0.8	Use gage
Wide Hollow Creek	5.0	30
Ahtanum Creek	3.0	20 See gage
Moxee Drain	3.0	20
East Toppenish Drain	5.0	Use gage
McDonald Drain	3.2	Use gage
Marion Drain	2.0	Use gage
Toppenish Creek	3.0	Use gage
Satus Creek	2.0	Use gage
Coulee Drain	3.0	Use gage
South Drain	3.0	Use gage
Ungage drains below Mabton	3.0	18
Granger Drain	3.0	50
Sulfur Creek	5.0	200
Sprink Creek	1.5	35
Snipe Creek	2.0	50

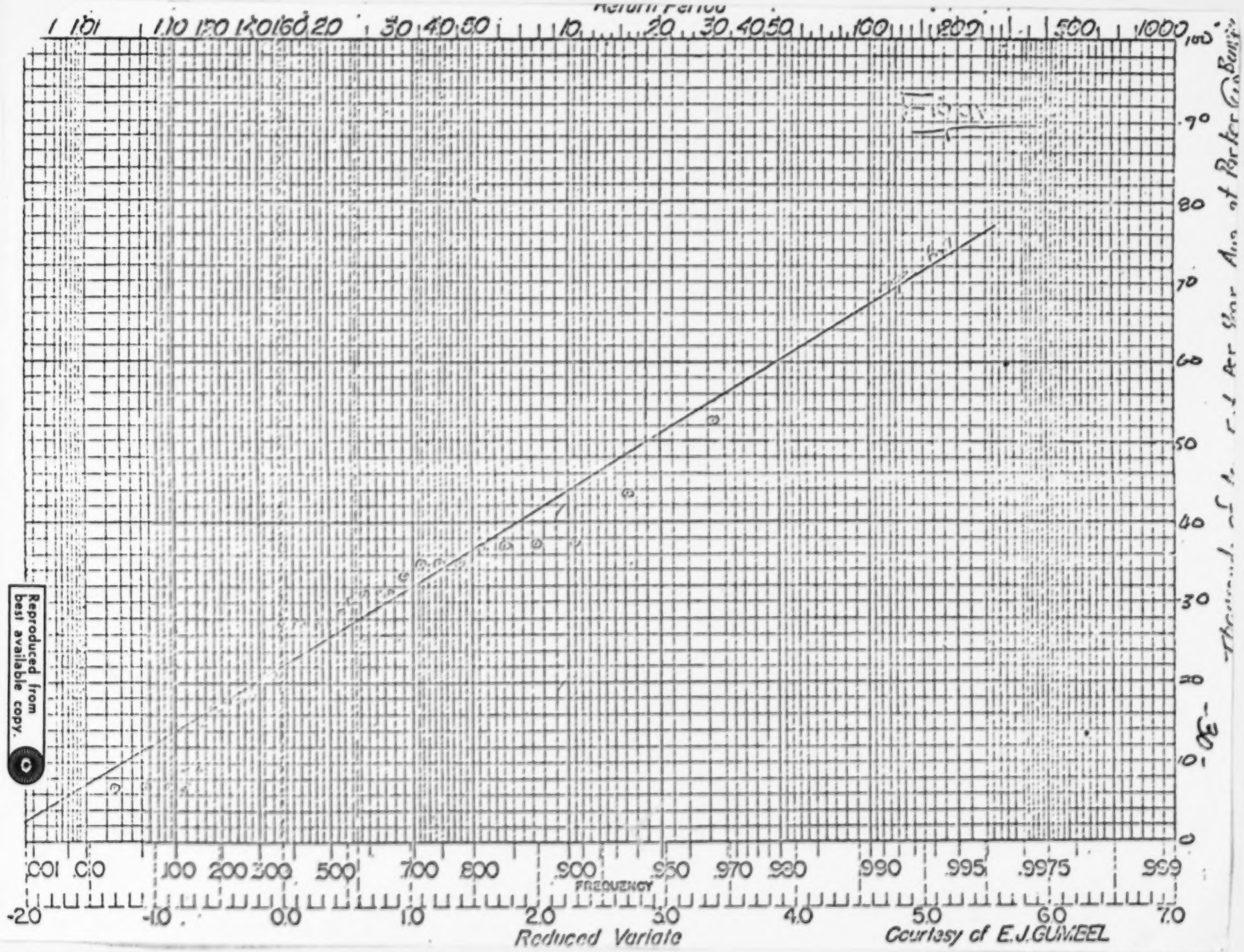

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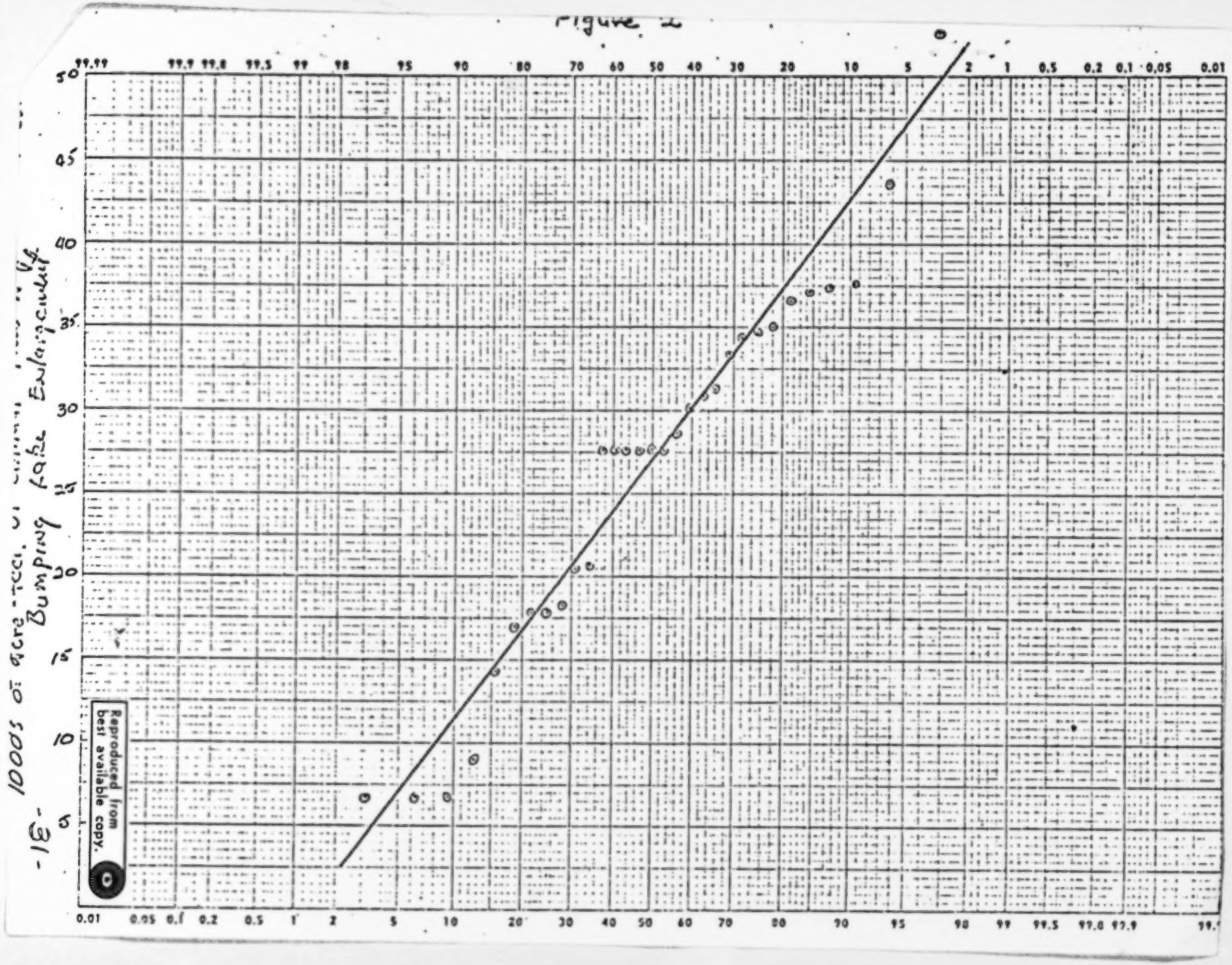
Figure 2



10005 of acceptable ... vs ... Bumping Rate Enlargement

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